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IUS GUIDANCE ALGORITHM GAMMA GUIDE ASSESSMENT

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**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Science and Engineering Directorate**

Under Contract NAS8-33197

Submitted By:

NORTHROP SERVICES, INC.

P. O. BOX 1484 Huntsville, Alabama 35807 (205) 837-0580

NSI

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GAMMA GUIDE ASSESSMENT**

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by

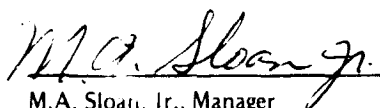
R.E. BRAY
V.A. DAURO

Prepared for:

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
SCIENCE AND ENGINEERING DIRECTORATE**

Under Contract NAS8-33197

Reviewed and approved by:



M.A. Sloan, Jr., Manager
Technology

**NORTHROP SERVICES, INC.
P.O. BOX 1484
HUNTSVILLE, ALABAMA 35807
(205)837-0580**

FOREWORD

This technical report documents the results of work performed by Northrop Services, Inc., Huntsville, Alabama, under Contract NAS8-33197 for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. The Contracting Officer's Representative (COR) for this study was Mr. A. W. Deaton of the Systems Analysis and Integration Laboratory, EL23.

ABSTRACT

The Inertial Upper Stage (IUS) will be guided by the Boeing Company's Gamma Guidance Algorithm. This report presents the results of an independent assessment of the algorithm's performance in satisfying the NASA missions' targeting objectives. The report includes an introduction to the algorithm, the results of a launch window analysis for a Galileo mission, and suggested improvements.

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LIST OF SYMBOLS

Symbol	Meaning
a	Semimajor axis of the target orbit
c_3	Twice target orbit energy
e	Target orbit eccentricity
G_o	Earth's gravity constant
i	Target orbit inclination
I_{sp}	Specific impulse
α	Thrust direction yaw angle
β	Thrust direction pitch angle
Δt	Impulse placement increment
Δv	Velocity change
η	Target orbit true anomaly
ω	Target orbit argument of perigee
ω_e	Earth spin rate
Ω	Target orbit ascending node angle

Acronyms

B-5	The onboard Gamma Guide Code
ECI	Earth centered inertial coordinates
IUS	Inertial Upper Stage
NSI	Northrop Services, Incorporated
PL13A	The NASA Galileo Mission
RCS	Reaction Control System
SAMBO	Simplex Algorithm for Multiple Burn Optimization
SRM	Solid Rocket Motor
WT3	Weight at End of SRM1 Burn
WT5	Weight at End of SRM2 Burn
WT9	Weight at End of SRM3 Burn
WTX	Weight at Beginning of SRM Burn

Section I

INTRODUCTION

1.1 GENERAL

The Boeing Company is developing an onboard adaptive guidance algorithm for the Inertial Upper Stage (IUS). This algorithm is called "Gamma Guidance", and it is designed to provide real-time guidance that will satisfy all DOD and NASA mission targeting objectives. Gamma Guide employs a sophisticated iterative approach to the guidance problem, and it uses numerical onboard integration for some nonlinear differential equations and closed form approximations for other nonlinear differential equations. It supplies ignition times and thrust attitude for the main stages' solid rocket motors (SRM), and ignition time, thrust attitude and termination times for corrective translational burns of the reaction control system (RCS).

The NASA planetary missions represent a different class of IUS missions when compared to DOD Earth Orbital Missions. Planetary missions require earth escape which results in hyperbolic orbits; thus, the targeting logic and convergence properties of the algorithm will be different than for the earth orbital elliptical trajectories. Gamma Guide has provisions for solving these classes of problems. The Gamma Guide algorithm has the following salient features.

1. It solves the two point boundary problem described by
 - o An initial position (moving with vehicle)
 - o A set of selectable constraints that include targeting end conditions
 - o A set of selectable controls encompassing ignition, attitude, and thrust profiles
 - o A set of nonlinear equations to propagate the equations of motion.
2. It generates ignitions times and steering angles for the Sol'd Rocket Motors (SRM);
3. It generates ignition times, steering angles and termination times for the Reaction Control System (RCS);
4. It is a real time, iterative, baseline guidance system that can satisfactorily solve the unique problem of using fixed impulse SRM's to power missions from near-earth to interplanetary orbits.

The algorithm has been under development for several years. References 1, 2, and 3 contain a comprehensive explanation of the algorithm. The referenced explanation includes derivation, approximations, and the assumptions used by or in the algorithm. Reference 4 contains selected portions of Reference 3 to familiarize the reader with the basic concepts of the guidance algorithm. Reference 4 also contains a listing of the double precision developmental code as modified for MSFC and the results of previous tests of the algorithm for several interplanetary missions and a geosynchronous mission.

The algorithm has been designed to guide many different types of missions. It is very flexible and the Boeing B-5 code for the onboard computer reflects this flexibility. The B-5 code, however, requires a driver code to simulate the inputs from the vehicle and the real world environment. The code is being revised as necessary and the current revision is revision I. A source program for this revision was obtained from Boeing, and was adapted to the MSFC UNIVAC 1100 computer systems by NSI.

A driver program for the B-5 code is not available, however as part of the B-5 simulation, Boeing supplied a six degree of freedom stand alone simulation (STARS) for attitude control of the IUS, that uses information supplied from the B-5 simulation. This code has been adapted by NSI to the MSFC UNIVAC 1100 system also.

The B-5 and the STARS code were adapted to the UNIVAC 1100 system, although this task was not an original part of the contract. This was done to replace Task VIII of the contract which required data not yet available for delivery by the government. The change was agreed to by the COR.

1.2 OBJECTIVES AND ACCOMPLISHMENTS

There were nine tasks assigned to this study. These tasks were a continuation of the basic tasks previously investigated in Reference 4, and are listed below with a brief discussion of their status.

1.2.1 Task 1. Update Testbed Programs

Requirement:

Make allowances for all discrete and analog inputs/outputs to/from the guidance algorithm that are required to assess the performance of the algorithm from a basic guidance standpoint in the guidance simulation program. Include the capability of simulating off-nominal variations in mainstage and RCS propulsion parameters, IUS mass properties, and initial position and velocity. Also, include the capability to simulate mainstage ignition failures. Variations in navigation parameters need not be simulated in this study; the measured position and velocity of the IUS can be set equal to the actual position and velocity.

Status:

The testbed program has been continually updated, and includes all of the detailed items required. During the course of this study, the code was changed to single precision calculations to simulate the on board computer.

1.2.2 Task 2. Maintain Testbed Guidance Algorithm

Requirement:

Maintain an up to date guidance algorithm consistent with the Boeing Aerospace Corporation latest changes.

Status:

NSI made one trip to Seattle to discuss with the Boeing representatives their latest changes to the algorithm. Additionally, NSI has kept in telephone communication and discussed with Boeing various suggestions for improvements to the code. The MSFC IUS team has been kept informed of the latest version. The improvements are presented in Section IV of this report.

1.2.3 Task 3. Identify Mission

Requirement:

Identify a group of off-nominal situations for each NASA IUS mission. For each situation, specify the variations in the propulsion, mass, and initial state parameters, and specify mainstage ignition failures. Each group of off-nominal situations should be representative of the anticipated three-sigma error volume. Form a covariance matrix using these error sources for each design reference mission.

Status:

The NASA missions have been in a state of change. The study was applied to the revised Galileo, and to the Venus Orbiter missions. Emphasis was placed on the Galileo mission as a representative of the basic NASA mission objectives. As part of this task, NSI investigated the preload data needed for the three on orbit launch opportunities for the first launch window of the Galileo mission. The results of this study were discussed in Section 3. The covariance matrix source program has been updated as necessary.

1.2.4 Task 4. Generate Quasioptimum Reference Trajectories**Requirement:**

Use SAMBO to generate quasioptimum reference trajectories for the nominal and off-nominal situations identified in Task 3, for each mission in the representative set of NASA IUS missions. These reference trajectories will provide a basis for the analyses of the gamma guided trajectories generated in Task 5.

Status:

SAMBO was used to generate the reference trajectories for the missions in Task 3. Changes were made to the SAMBO code to calculate and output additional data needed for the MSFC Gamma Guide Code. The SAMBO changes are discussed in Section VI of this report.

1.2.5 Task 5. Analyze**Requirement:**

Analyze the gamma guided trajectories from Task 3 and record the targeting accuracies, RCS propellant usages, and any abnormalities in trajectory profiles or attitude histories as compared to the SAMBO trajectories generated in Task 4. Identify those trajectories that do not satisfy the targeting accuracy requirements, RCS propellant budgets, basic sequencing and timing requirements, or attitude-rate constraints.

Status:

This task was modified because the NASA missions do not use RCS burns for corrective action. The trajectories were in general well within the

targeting accuracies. Some problems were found in basic sequencing. These were discussed with Boeing and have been rectified by the addition of a time-line checking sequence in the MSFC code.

1.2.6 Task 6. Patch and Repair as Necessary

Requirement:

For each of the unsatisfactory gamma guided trajectories (if any) identified in Task 5, define and incorporate modifications to the gamma guidance logic (Fortran version) that will produce a satisfactory trajectory in the same situation. Verify that the modifications are sufficient by using the simulator testbed (with the modified guidance logic) to generate a satisfactory trajectory.

Status:

All problems encountered were eliminated by adding appropriate coding. These changes were discussed with Boeing for possible inclusion in their B-5 Fortran version of the on board code. These changes are presented also in Section IV.

1.2.7 Task 7. Document

Requirement:

Document the results of the study in a final report. In addition to a general assessment of the Gamma Guidance algorithm, document the results on a mission-by-mission basis. Include all suggested modifications to the guidance algorithm in a separate section of the report.

Status:

This report is in response to this task. In addition Reference 5 was used to document the results of a study of the preload date of the PL13A Galileo probe.

1.2.8 Task 8. Modify the 6-D Program (IUS-SIXD)

Requirement:

Modify the six degrees of freedom spin stage computer simulation program built during the first contract to include the RCS spin-up control system,

the characteristics of the hydrazine blow-down system, the gyro data sampling and processing characteristics, and the open loop part of the spin-up after system saturation. Documentation of the software and program users manual shall be in compliance with FIPS Publication 38.

Status:

The six degrees of freedom spin stage simulation program SIXD of Reference 10 was modified to include the basis for an RCS spin up system. However, the data required for completing this task was and is not available. To replace this task, the COR requested and NSI added the adaptations of the Boeing B-5 Revision I Fortran version of the on board code to the MSFC UNIVAC 1100 computer system.

The B-5 code requires a driver code to simulate the inputs from the vehicle and the real world environment. The driver program is not available, however as part of the B-5 simulation, Boeing supplied a six degree of freedom stand alone simulation (STARS) for attitude control of the IUS. This simulation was also adapted by NSI to the MSFC UNIVAC 1100 system. Although the B-5 driver is not available, the programming can be verified by judicious use of the MSFC developmental code.

1.2.9 Task 9. Provide Mission Analysis Support

Requirement:

Provide a limited (no more than 20% of the manpower) amount of analysis to support the MSFC/JSC IUS mission planning activities as directed by the MSFC contracting officer's representative.

Status:

NSI accompanied the COR to JSC Houston. NSI delivered and discussed the latest version of the MSFC Gamma Guide Development code with JSC IUS personnel.

1.3 DEVELOPMENT CODE PHASES, STAGES AND TIMELINE

In continuing the assessment of the algorithm, the developmental code of Reference 4 was used. This double precision code has been obtained from Boeing in 1978 and has been modified and improved by NSI. This development

code simulates the vehicle and real world input to the algorithm and is used as a test bed for changes to the algorithm. During this study, the code was changed to single precision, so that a closer simulation to the ultimate onboard version would be obtained.

The MSFC code has provision for six phases plus a terminal coast. Each phase consists of a coast arc followed by a burn arc for a total of 13 stages when the terminal coast is included. These are shown in Figure 1-1. Also included in Figure 1-1 is the relation of the event timeline to the Gamma Guide controls λ which are shown in Figure 1-2. The development code is not as flexible as the B-5 code in that the timeline must reflect an RCS burn between two SRM burns. This is not fatal, however, since a zero second burn is allowed.

A simplified flow chart of the MSFC code is given in Figure 1-3. This figure also incorporates several improvements suggested in Section IV of this report.

1.4 REPORT SECTION DESCRIPTIONS

Section II of this report is a brief discussion of the type of data needed by the MSFC Gamma Guide simulation and the differences between the data required by the MSFC and Boeing B-5 codes.

Section III is a report of the data used in the launch window analysis of the Galileo mission PL13A. A preliminary report of the analysis was contained in Reference 5. Data from References 6 and 7 were also used in the analysis.

Section IV is composed of suggested improvements to the algorithm. These have been discussed with the Boeing Company's representative involved in coding their B-5 simulation.

Section V discusses the availability of source listings and cards for the various codes used in this study.

Section VI is a report of changes to the computer code SAMBO of Reference 8. These changes were made to facilitate the generating of reference trajectories.

Section VII contains the references list.

	TERM.	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀	T ₁₁	T ₁₂	T ₁₃
PHASE		1	2	3	4	5	6	7	8	9	10	11	12	
STAGE	1	2	3	4	5	6	7	8	9	10	11	12	13	
EVEN	COAST	SRM 1	COAST	RCS 1	COAST	SRM 2	COAST	RCS 2	COAST	SRM 3	COAST	RCS 3	COAST	
IMPULSE		$\lambda_1 \cdot \lambda_2 \cdot \lambda_3$		$\lambda_5 \cdot \lambda_6 \cdot \lambda_7$		$\lambda_9 \cdot \lambda_{10} \cdot \lambda_{11}$		$\lambda_{13} \cdot \lambda_{14} \cdot \lambda_{15}$		$\lambda_{17} \cdot \lambda_{18} \cdot \lambda_{19}$		$\lambda_{21} \cdot \lambda_{22} \cdot \lambda_{23}$		
IMPULSE TIME		λ_4		λ_8		λ_{12}		λ_{16}		λ_{20}		λ_{24}		
STAGE TIME	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀	T ₁₁	T ₁₂	T ₁₃	

NOTE: The terminal coast may be used to coast cases to a common end time.

Figure 1-1. GAMMA GUIDE PHASES, STAGES, AND TIMES

LAMBDA	CONTROL*
1	$\Delta \dot{X}$
2	$\Delta \dot{Y}$
3	$\Delta \dot{Z}$
4	T_{S1}
5	$\Delta \dot{X}$
6	$\Delta \dot{Y}$
7	$\Delta \dot{Z}$
8	T_{R1}
9	$\Delta \dot{X}$
10	$\Delta \dot{Y}$
11	$\Delta \dot{Z}$
12	T_{S2}
13	$\Delta \dot{X}$
14	$\Delta \dot{Y}$
15	$\Delta \dot{Z}$
16	T_{R2}
17	$\Delta \dot{X}$
18	$\Delta \dot{Y}$
19	$\Delta \dot{Z}$
20	T_{S3}
21	$\Delta \dot{X}$
22	$\Delta \dot{Y}$
23	$\Delta \dot{Z}$
24	T_{R3}

*VELOCITY DELTAS AND IGNITION TIME

Figure 1-2. GAMMA GUIDE CONTROLS

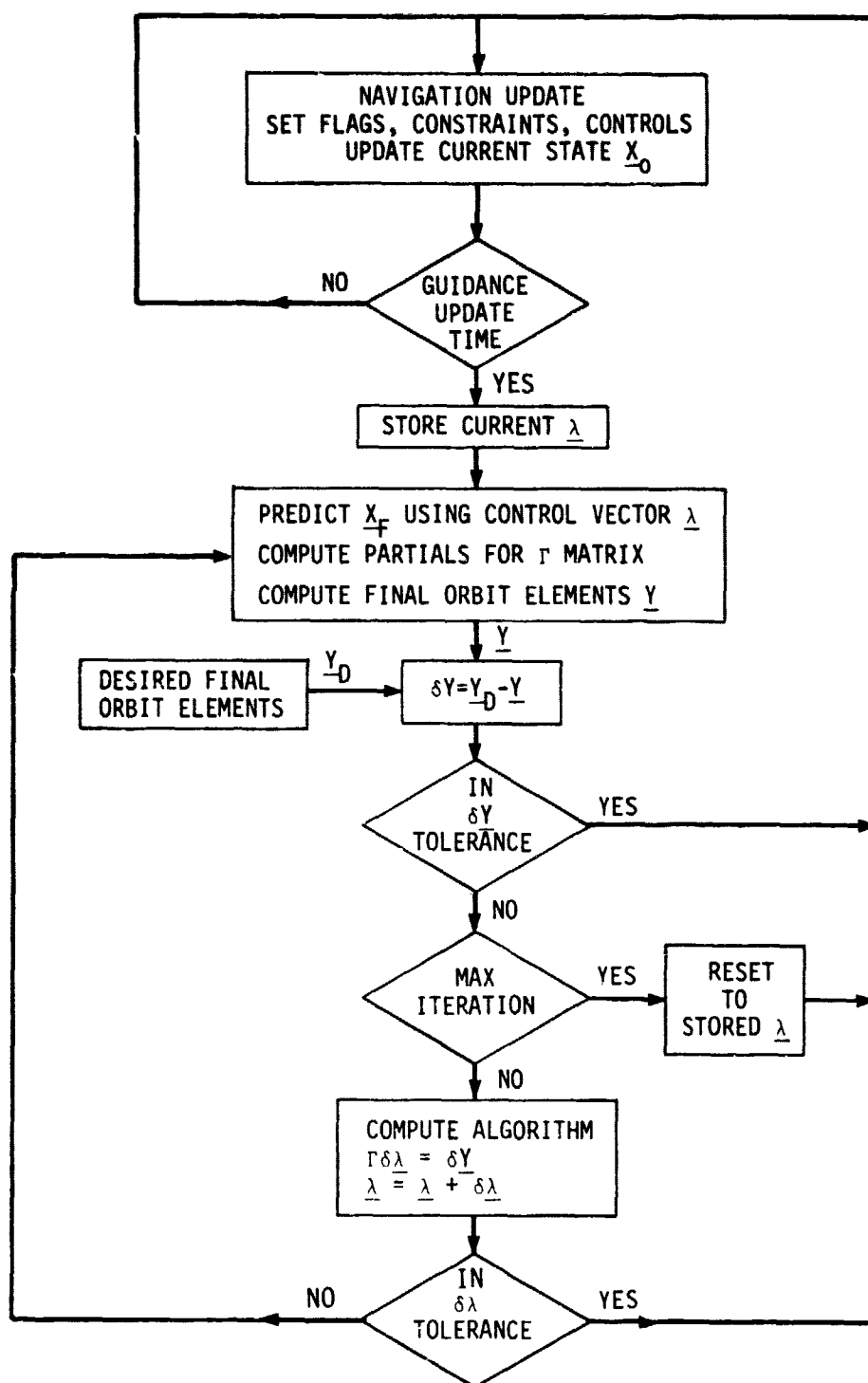


Figure 1-3. GAMMA GUIDE SIMPLIFIED FLOW

Section II

PRELOAD DATA

2.1 DEVELOPMENT VERSUS ONBOARD CODE

There are two versions of the GAMMA GUIDE algorithm code. These are: the developmental code modified for use on the Univac 1108 computer system at MSFC, and the B-5 Revision I code being developed by Boeing for the onboard computer. In general, the preload data is the same for both codes, however, certain differences in data form and usage exists. These differences are shown in Table I. The remainder of this section applies to the data input to the MSFC code.

Table I

BASIC DIFFERENCES INPUT DATA

DATA	MSFC CODE	B-5 CODE
Δt for impulse placement	Integrated from thrust table input	Calculated from input polynomial
Target Conic	Inertial coordinates or conic parameter input without retargeting	Retargeting using polynomial input
Real World, Gravity, Thrust, etc.	Input for simulation	Sensed through NAV system
Times	Referenced to program time zero	Referenced to GMT and/or nominal launch time
Control Lambdas	Discrete data points, referenced to inertial system at time zero. No retargeting	Retargeting with polynomials referenced to nominal launch times and on-orbit delays.

2.2 MSFC SIMULATION

A complete description of the input data to the MSFC code can be found in Reference 4. Additionally Reference 5 contains a discussion of targeting preset data for the Galileo mission. Portions of References 4 and 5 are included here as an introduction. A broad overview of the preload data required

by the MSFC GAMMA GUIDE simulation program is shown in Table 2. The data is divided into 3 categories. Types I and II are the preload needed by the algorithm, while Type III simulates the real world aspects for supplying navigational data for the algorithm.

Table 2

INPUT DATA TYPES

I. NOMINAL NON-CONTROL PRELOAD

- Initial position
- Target orbital data
- Various control flags
- Predicted SRM thrust tables
 - " SRM burn time
 - " RCS ISP
 - " RCS thrust equation constants
 - " Drop weights
 - " Stage weights

Used "as is" by the algorithm with (type II below) to predict future states.

II. NOMINAL CONTROLS (Lambda's)

- Impulsive delta velocities
- Impulse times

Modified by the algorithm and used with (type I above) to predict future states.

III. NAVIGATION DATA FOR SIMULATION

- SRM thrust tables
- SRM ISP's
- SRM burn times
- RCS ISP
- RCS thrust equation constants

Used by the navigation system with the computed controls of (type II above) to update the actual state.

A listing of a sample case input for the MSFC code is contained in Appendix A.

Section III

PL13A GALILEO PROBE

3.1 MISSION PROFILE

The following mission scenario and ground rules are extracted from Reference 6.

Begin Quotation:

A. Mission Scenario

Before going into the details of the launch window trajectory generation, it would be helpful to summarize the salient features of the Space Transportation System (STS) and the Galileo mission. The IUS/Galileo spacecraft will be carried to a deployment orbit by the Space Shuttle. The first two burns of the Space Shuttle Orbiter On-orbit Maneuvering System (OMS) will place the Orbiter/cargo into an 100 x 100 nmi orbit. After 3 to 4 revolutions in the 100 x 100 nmi orbit, a third OMS burn will place the Orbiter/cargo into a 100 x 250 nmi deployment orbit. After deployment of the IUS/SC, the IUS, which is made up of two large solid propellant motors (21,000 lbs. class) and one small spin stabilized solid propellant motor (6,000 lbs. class), will execute the 1st large motor burn across perigee of the deployment orbit and thereby place the IUS/SC into a 100 x 3200 nmi elliptical transfer orbit. After approximately one revolution the 2nd large motor will ignite and burn to cut-off. The 3rd solid propellant motor will ignite upon completion of a 270 second coast period. The 270 second coast period will be varied to compensate for over/under performing motors. The 3rd stage is spin stabilized to 70 RPM with the Reaction Control System (RCS). The 2nd stage and RCS/avionics section is staged prior to 3rd stage ignition for ΔV efficiency. Upon completing the 3rd stage burn, the spacecraft will despin the configuration. Approximately 10 days later the S/C will execute a ΔV course correction to enable the S/C to swing-by the planet Mars on the way to the planet Jupiter. Upon arriving at Jupiter (approximately 3 1/2 years later), the Galileo spacecraft will brake into orbit about Jupiter and encounter several of the Jovian satellites.

B. Space Shuttle Orbiter/IUS/SC Groundrules and Assumptions

The integrated Orbiter/IUS trajectories for the January 4, 1982, to January 14, 1982, Galileo mission launch period were generated under the following groundrules and assumptions for the Orbiter, IUS, and S/C:

ORBITER:

1. Approximate Midnight Launch (1/4/82 - 1/14/82)
2. The daily launch window should be defined as that period of time determined by the launch azimuth constraints of $85^\circ \leq AZ \leq 95^\circ$.
3. No yaw steering requirements shall be imposed by the planetary targeting objectives. However, any real time launch environment or vehicle perturbation that causes a drift out of a plane will have to be corrected by Space Shuttle yaw steering.
4. The Space Shuttle flight profile shall use a two OMS burns ascent to a 100 x 100 nmi orbit followed by a minimum coast time of 4.5 hours prior to the third OMS burn that achieves the 100 x 250 nmi IUS/SC deployment orbit.
5. The minimum coast between Orbiter insertion into the 100 x 250 nmi deployment orbit and IUS/SC deployment shall be 3 REVS in orbit.
6. The Orbiter shall provide the IUS initialization data (time, position, velocity, and IMU alignment angles) to the IUS computer prior to deployment.
7. The Orbiter shall provide pointing during the coast phase prior to deployment consistent with the thermal conditioning requirements of the IUS/SC.
8. The Orbiter shall provide the translational ΔV for the IUS/SC separation after deployment and prior to the IUS first stage ignition.

IUS:

1. The IUS first stage propellant off-load shall be determined from the following conditions:
 - a. Maximum C_3 of the launch period.
 - b. The third on-orbit launch opportunity.
 - c. 30 second on-orbit ignition delay of the first SRM.
2. Reference trajectories shall be developed for the 1st day of the launch period, fifth day, and last day.
3. The tracking analysis shall be based on the reference trajectories from the fifth day, launch azimuths of 85° , 90° , and 95° and the first, second, and third on-orbit launch opportunities.
4. The guidance (steering) analysis shall be based on the minimum C_3 launch period (energy management exercised), and the third on-orbit launch opportunity.
5. The navigation analysis shall be based on the minimum C_3 launch period, and the 3rd on-orbit launch opportunity.
6. The spin stage accuracy analysis shall be based on the minimum C_3 launch period, and the 3rd on-orbit launch opportunity.

7. The IUS/SC deployment state shall reflect the Space Shuttle ascent profile to a 100 x 100 nmi orbit and subsequent 100 x 250 nmi deployment orbit.

GALILEO SPACECRAFT:

1. 2060 kilogram spacecraft
2. Project Galileo Targeting Specifications (625-120 dated 9/15/78).

End Quotation.

This mission starts from a low parking orbit, with an SRM burn at perigee to transfer to a higher energy elliptical orbit, coasts back to perigee, then has a second SRM burn followed by a coast, and then the third SRM burn which injects into a hyperbolic orbit that goes to Jupiter. The mission is shown in Figure 3-1 and further described in Reference 6.

The launch azimuths for this mission are restricted to the range from 85 to 95 degrees and there are three on-orbit launch opportunities for each window. The first opportunity is a dog leg to the left maneuver, occurring approximately one orbit before the nominal in plane opportunity for the daily launch window. The third opportunity is a dog leg to the right maneuver occurring approximately one orbit after the nominal. The launch window and opportunity selected will determine the preload values needed for the simulation. Most of the data described in Section II remains fixed. The variable data include:

- o The initial state (position, velocity),
- o The predicted stage weights,
- o The target orbital data (desired mission constraint values),
- o The time at which the mission constraints are evaluated,
- o The nominal controls (Lambdas) which include the impulsive delta velocity and impulse time for each SRM burn (RCS also if used).

The B-5 onboard code will have provisions for updating these as a function of launch time and on-orbit delay. The study described in Reference 5 was undertaken to test the feasibility of the retargeting procedures described in Reference 7.

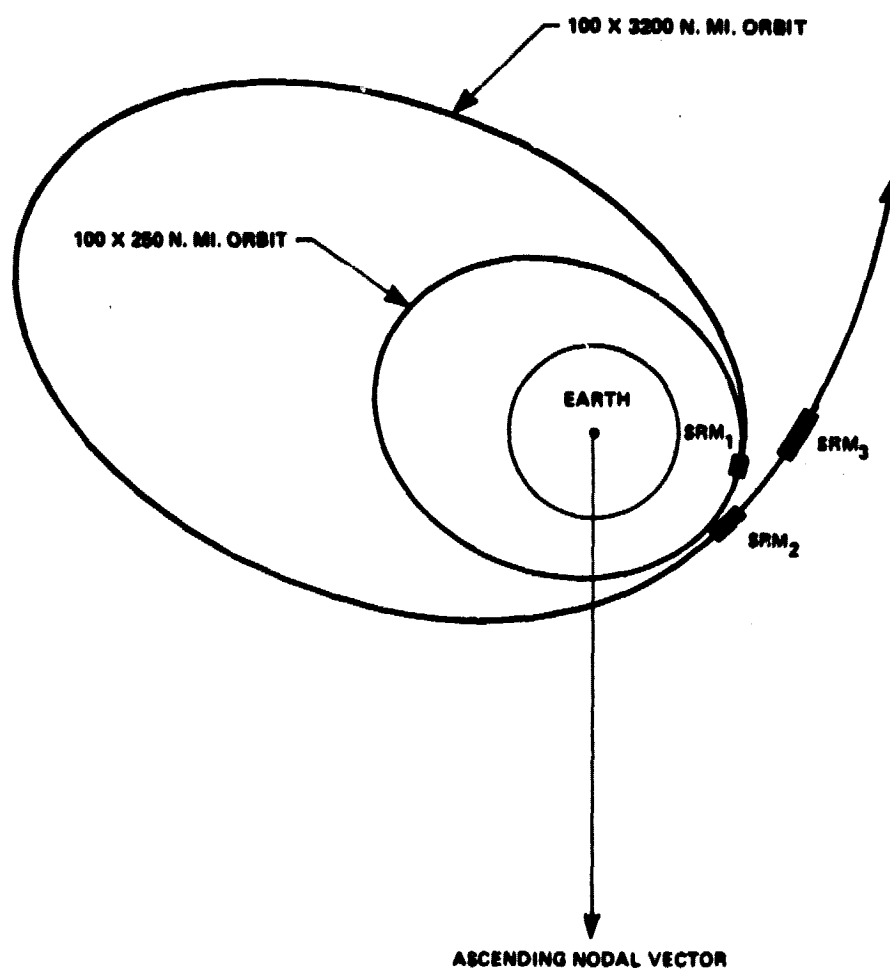


Figure 3-1. GALILEO PROBE $C3 = 65 \text{ KM}^2/\text{SEC}^2$

3.2 GENERATION OF PRELOAD DATA

The program SAMBO (Simplex Algorithm for Multiple Burn Optimization, Reference 8) was used, with data from Reference 6, to generate reference trajectories for the Galileo Mission PL13A. Using azimuths of 85.0, 87.5, 90.0, 92.5, and 95.0 degrees, references were obtained for the three opportunities of the first launch window. The data from these runs were then used as trial data load for GAMMA GUIDE. These 15 cases all ran satisfactorily using at most four iterations to converge on the first (pre SRM1) solution. The converged data is shown in Tables 3, 4, 5, and 6. This data can be divided into:

- o Predicted Stage Weights
- o Target Conic Elements
- o Control Values
- o Initial State

3.2.1 Predicted Stage Weights

These values are shown in Table 3 and are used to predict ΔV output from each SRM. The ΔV from SRM1 may be input as DELV1. If not input it will be calculated internally by

$$\Delta V1 = G_0 \text{ Isp}_1 \ln \left(\frac{WT3}{WTX} \right)$$

The values of $\Delta V2$ and $\Delta V3$ are obtained, in the MSFC version, from the predicted thrust tables for the SRM. In this study, it was found that the values of the predicted stage weights and $\Delta V1$ for opportunity 2 could be used as estimates for opportunities 1 and 3 also. Note that this implies that these values can be fixed or set as a function of the window only.

Table 3. PREDICTED STAGE WEIGHTS AND $\Delta V1$

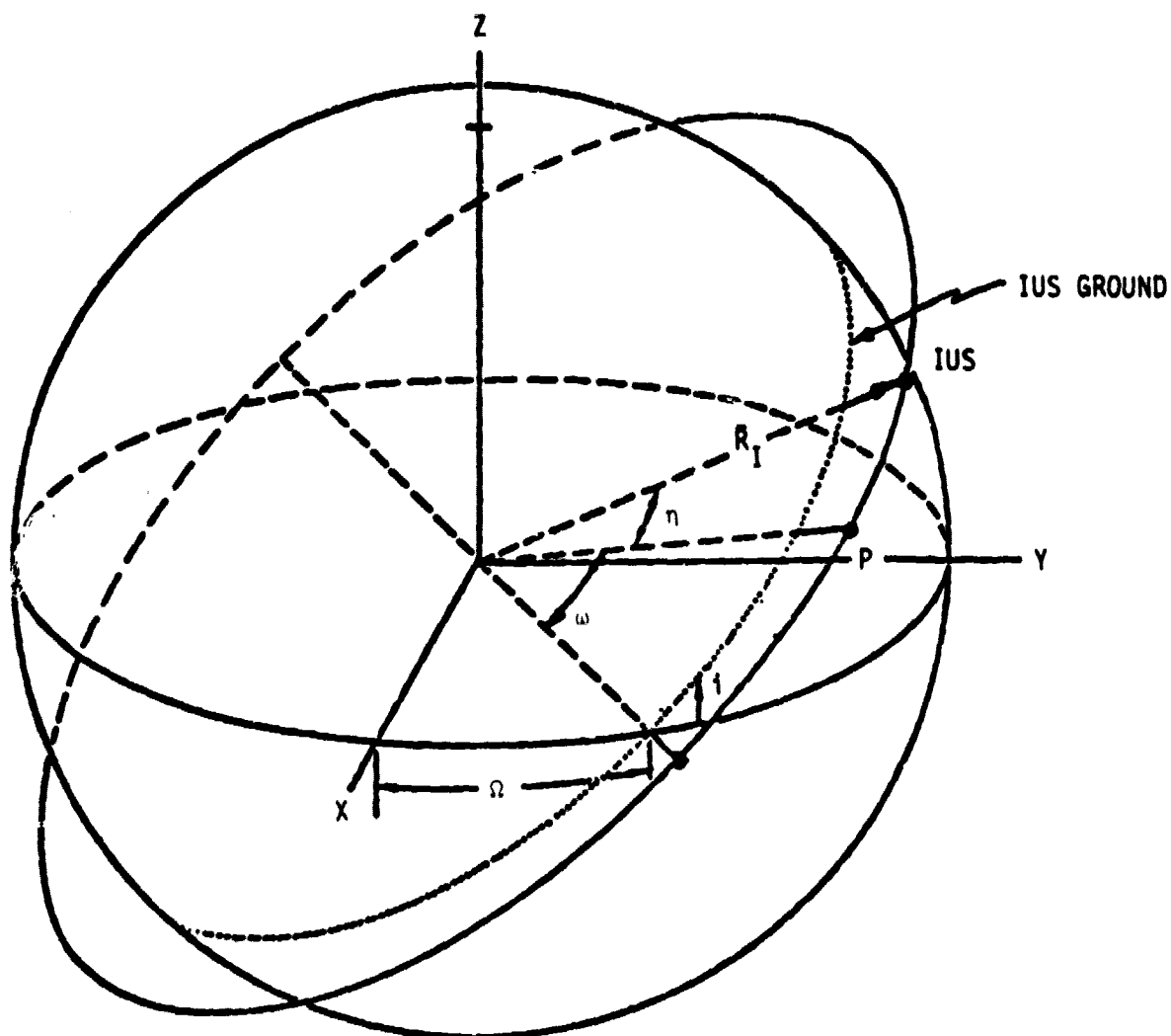
	OPPORTUNITY		
	1	2	3
$\Delta V1$	3390.09	3391.00	3391.89
WT3	55497.41	55485.72	55473.60
WTX	38774.55	38762.56	38750.43
WT5	36502.46	36490.47	36478.35
WT9	11347.48	11347.48	11347.48

3.2.2 Target Conic Elements

The target conic elements are referenced to the inertial coordinate system which is established at program time zero. The elements are defined in Figure 3-2 and their values are given in Tables 4, 5 and 6. They are:

- o a Semimajor axis,
- o e Eccentricity,
- o i Inclination,
- o ω Argument of Perigee,
- o Ω Ascending Nodal Angle,
- o η True Anomaly,
- o TIME Time.

It should be noted that these variables are almost all constant as a function of the azimuth. The exception is the ascending nodal angle which varies as a function of time and the earth's rotation rate. This is a result of the inertial coordinate system being fixed at time zero. The target orbital data was therefore revised to the averages shown in Table 7.



- \bar{R}_I IUS Position Vector (Navigation System)
- X,Y,Z Basic Earth Centered Inertial (ECI)
Coordinate System For Guidance Computations
- i Inclination of the Target Orbit
- P Perigee of the Target Orbit
- ω Argument of Perigee
- Ω Right Ascension of the Ascending Node
- η True Anomaly--Vehicle Position with Respect to Perigee

Figure 3-2. THE GUIDANCE COORDINATE SYSTEM AND THE TARGET ORBIT DEFINITION

Table 4. PRELOAD DATA OPPORTUNITY 1

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123394.	-20123565.	-20123610.	-20123535.	-20123306.
e	2.08902	2.08851	2.08854	2.08894	2.08895
i	28.74128	28.44463	28.38710	28.52936	28.85784
ω	71.03187	71.11817	71.13730	71.09830	70.99561
Ω	-83.91125	-89.22364	-94.15586	-99.72639	-104.47325
η	93.88314	93.88172	93.88706	93.87489	93.87757
TIME	32793.194	32761.315	32827.780	32763.585	32734.073
SRM1	564.279	862.829	1124.971	1434.276	1697.215
	3307.939	3243.353	3162.892	3034.395	2892.983
	482.618	478.435	472.507	477.500	492.769
RCS1	21480.817	21447.048	21522.686	21449.185	21415.109
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	21700.000	21700.000	21700.000	21700.000	21700.000
	2492.530	3186.984	3844.230	4536.497	5081.109
	7833.290	7594.572	7283.257	6867.268	6468.035
	1807.259	1733.633	1736.647	1760.881	1785.144
RCS2	30343.326	30312.416	30377.528	30314.507	30285.543
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	30500.000	30500.000	30500.000	30500.000	30500.000
	570.484	1248.078	1883.199	2564.647	3131.560
	7430.248	7345.703	7208.782	6997.184	6760.895
	662.945	675.635	678.638	659.949	676.140
RCS3	30771.298	30739.840	30804.508	30742.509	30713.912
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	30900.000	30900.000	30900.000	30900.000	30900.000

Table 5. PRELOAD DATA OPPORTUNITY 2

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123433.	-20123585.	-20123638.	-20123518.	-20123301.
e	2.08903	2.08909	2.08886	2.08897	2.08911
i	28.78027	28.50794	28.45868	28.58700	28.92210
ω	71.02190	71.10731	71.11900	71.08086	70.97851
Ω	-83.89813	-89.20139	-94.13065	-99.70639	-104.45130
η	93.81627	93.81659	93.81559	93.80801	93.81846
TIME	38236.095	38207.145	38270.043	38206.236	38178.755
SRM1	LAMBDA				
	493.928	794.674	1075.524	1374.853	1634.714
	3320.712	3263.308	3181.720	3064.756	2931.017
	477.270	467.112	467.748	464.684	485.522
RCS1	26955.941	26926.026	26990.399	26922.820	26895.121
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	27100.000	27100.000	27100.000	27100.000	27100.000
	2494.239	3213.331	3832.206	4524.153	5084.876
	7834.950	7575.097	7282.780	6872.950	6458.329
	1818.459	1790.775	1786.012	1791.385	1829.888
RCS2	35784.786	35756.336	35821.091	35756.588	35727.872
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	36000.000	36000.000	36000.000	36000.000	36000.000
	571.474	1248.107	1869.960	2566.045	3142.580
	7422.201	7339.000	7206.725	6988.942	6747.943
	746.914	744.876	734.778	737.311	750.323
RCS3	36210.001	36181.807	36247.295	36182.132	36153.426
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	36400.000	36400.000	36400.000	36400.000	36400.000

Table 6. PRELOAD DATA OPPORTUNITY 3

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123372.	-20123559.	-20123513.	-20123510.	-20123293.
e	2.08940	2.08936	2.08934	2.08950	2.08940
i	28.84632	28.57597	28.53044	28.66552	28.98812
ω	71.00761	71.08931	71.10343	71.06429	70.96465
Ω	-83.87525	-89.17751	-94.10520	-99.67873	-104.42870
η	93.77559	93.77507	93.77322	93.77107	93.77535
TIME	43682.289	43651.951	43716.746	43654.470	43625.131
	LAMBDA				
SRM1	450.691	769.654	1037.313	1341.030	1600.123
	3325.723	3267.958	3194.374	3080.447	2951.659
	491.287	482.136	474.210	466.266	481.909
RCS1	32421.662	32384.079	32460.816	32392.894	32361.522
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	32600.000	32600.000	32600.000	32600.000	32600.000
	2492.149	3200.212	3833.147	4530.155	5077.330
	7830.394	7575.399	7273.460	6855.897	6456.724
	1861.726	1833.705	1842.349	1861.418	1876.684
RCS2	41230.032	41203.317	41264.071	41202.809	41173.310
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	41400.000	41400.000	41400.000	41400.000	41400.000
	562.646	1226.614	1855.110	2559.034	3128.397
	7417.371	7337.378	7205.174	6985.342	6746.925
	799.725	794.876	785.853	793.648	815.883
RCS3	41654.073	41629.673	41687.753	41627.153	41597.490
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	41800.000	41800.000	41800.000	41800.000	41800.000

Table 7

REVISED TARGET ORBITAL DATA

Semimajor axis	a	-20123482
Eccentricity	e	2.08879
Inclination	i	28.59204
Argument of Perigee	ω	71.07624
True Anomaly	η	93.88088

ASCENDING NODE ANGLE

AZIMUTH	OPP1	OPP2	OPP3
85.0	-83.91125	-83.98913	-83.87525
87.5	-89.22364	-89.20139	-89.17751
90.0	-94.15586	-94.13065	-94.10520
92.5	-99.72639	-99.70639	-99.67873
95.0	-104.47325	-104.45130	-104.37535

3.2.3 Control Lambdas

The converged values of the control variables are shown in Tables 4, 5, and 6. The RCS values of zero are needed by the MSFC code, but are not used by the B-5 code.

The data for the SRM1 burn were then modified to reflect a uniform ΔV of 3391 ft/sec corresponding to the value for Opportunity 2. Uniform times for the RCS burns were also set. The reduced data are shown in Tables 8, 9, and 10.

3.2.4 Initial State

The initial state values for the MSFC simulation are as shown in Table 11. These values were used as functions of the launch azimuths.

Table 8. REDUCED PRELOAD DATA OPPORTUNITY 1

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123482.	-20123482.	-20123482.	-20123482.	-20123482.
e	2.08879	2.08879	2.08879	2.08879	2.08879
i	28.59204	28.59204	28.59204	28.59204	28.59204
ω	71.07624	71.07624	71.07624	71.07624	71.07624
Ω	-83.91125	-89.22364	-94.15586	-99.72639	-104.47325
η	93.88088	93.88088	93.88088	93.88088	93.88088
TIME	32800.000	32800.000	32800.000	32800.000	32800.000
	LMBDAS				
SRM1	507.762	815.378	1099.277	1394.472	1645.004
	3323.213	3264.553	3180.358	3062.026	2929.821
	444.200	420.395	419.279	422.288	457.159
RCS1	21479.999	21444.785	21519.424	21445.363	21415.944
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	21700.000	21700.000	21700.000	21700.000	21700.000
	2503.769	3227.857	3847.976	4538.167	5092.162
	7837.069	7576.312	7282.450	6871.069	6458.006
	1796.095	1759.231	1753.132	1762.932	1810.667
RCS2	30348.369	30316.563	30376.794	30316.119	30294.207
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	30500.000	30500.000	30500.000	30500.000	30500.000
	588.365	1272.996	1896.702	2589.285	3155.699
	7424.354	7339.648	7204.901	6985.030	5745.098
	711.566	694.680	682.242	691.731	720.246
RCS3	30780.728	30748.823	30807.255	30747.832	30727.746
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	30900.000	30900.000	30900.000	30900.000	30900.000

Table 9. REDUCED PRELOAD DATA OPPORTUNITY 2

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123482.	-20123482.	-20123482.	-20123482.	-20123482.
e	2.08879	2.08879	2.08879	2.08879	2.08879
i	28.59204	28.59204	28.59204	28.59204	28.59204
ω	71.07624	71.07624	71.07624	71.07624	71.07624
Ω	-83.89813	-89.20139	-94.13065	-99.70639	-104.45130
n	93.88088	93.88088	93.88088	93.88088	93.88088
TIME	38200.000	38200.000	38200.000	38200.000	38200.000
	LAMBDA				
SRM1	488.997	796.876	1080.826	1374.986	1628.133
	3320.219	3263.311	3181.318	3064.730	2932.811
	485.706	463.327	458.162	464.458	496.676
	26957.794	26925.177	26989.444	26922.758	26898.726
RCS1	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	27100.000	27100.000	27100.000	27100.000	27100.000
	2490.701	3214.909	3835.928	4524.249	5080.131
	7834.806	7575.007	7282.398	6872.925	5460.033
	1823.924	1788.324	1779.550	1791.239	1837.036
	35786.545	35755.527	35819.490	35756.532	35730.657
RCS2	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	36000.000	36000.000	36000.000	36000.000	36000.000
	566.040	1250.538	1875.726	2566.193	3135.269
	7421.704	7338.996	7206.265	6988.914	6750.006
	755.939	740.826	724.522	737.069	762.256
	36212.001	36180.848	36246.711	36182.055	36157.790
RCS3	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	36400.000	36400.000	36400.000	36400.000	36400.000

Table 10. REDUCED PRELOAD DATA OPPORTUNITY 3

LAUNCH AZIMUTH	85.00	87.50	90.00	92.50	95.00
	TARGET ORBITAL ELEMENTS				
a	-20123482.	-20123482.	-20123482.	-20123482.	-20123482.
e	2.08879	2.08879	2.08879	2.08879	2.08879
i	28.59204	28.59204	28.59204	28.59204	28.59204
ω	71.07624	71.07624	71.07624	71.07624	71.07624
Ω	-83.87525	-89.17751	-94.10520	-99.67873	-104.77535
n	93.88088	93.88088	93.88088	93.88088	93.88088
TIME	43600.000	43600.000	43600.000	43600.000	43600.000
	LMBDAS				
SRM1	467.580	774.411	1057.406	1353.839	1629.909
	3316.858	3262.550	3182.243	3067.298	2931.540
	527.925	504.910	504.090	507.624	498.350
	32420.547	32381.911	32455.901	32388.095	32352.282
RCS1	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM2	32600.000	32600.000	32600.000	32600.000	32600.000
	2477.293	3200.042	3820.331	4511.099	5082.794
	7832.539	7574.835	7283.194	6874.069	6457.372
	1851.705	1815.510	1809.592	1819.788	1839.026
	41229.583	41202.458	41260.902	41199.348	41165.838
RCS2	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
SRM3	41400.000	41400.000	41400.000	41400.000	41400.000
	543.202	1226.358	1850.313	2543.662	3137.931
	7418.726	7338.477	7207.800	6992.179	6748.550
	41650.240	41625.296	41680.803	41619.686	41585.720
RCS3	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	.000	.000	.000	.000	.000
	41800.000	41800.000	41800.000	41800.000	41800.000

Table 11. INITIAL STATE

	AZIMUTH				
	85.0	87.5	90.0	92.5	95.0
LAT	28.63360	28.249024	28.40993	28.33325	28.495628
LON	14.84890	11.85565	1.87490	1.28092	358.76512
ALT	617800.6	622245.4	618443.9	622255.58	626278.21
AZM	92.95830	94.02688	91.62042	93.98590	95.12122
GAMMA	.43980	.46922	.44485	.46696	.49189
VEL	25815.41	.2581035	25814.70	25810.31	25805.58

3.3 INTERPOLATION FOR OTHER LAUNCH AZIMUTHS

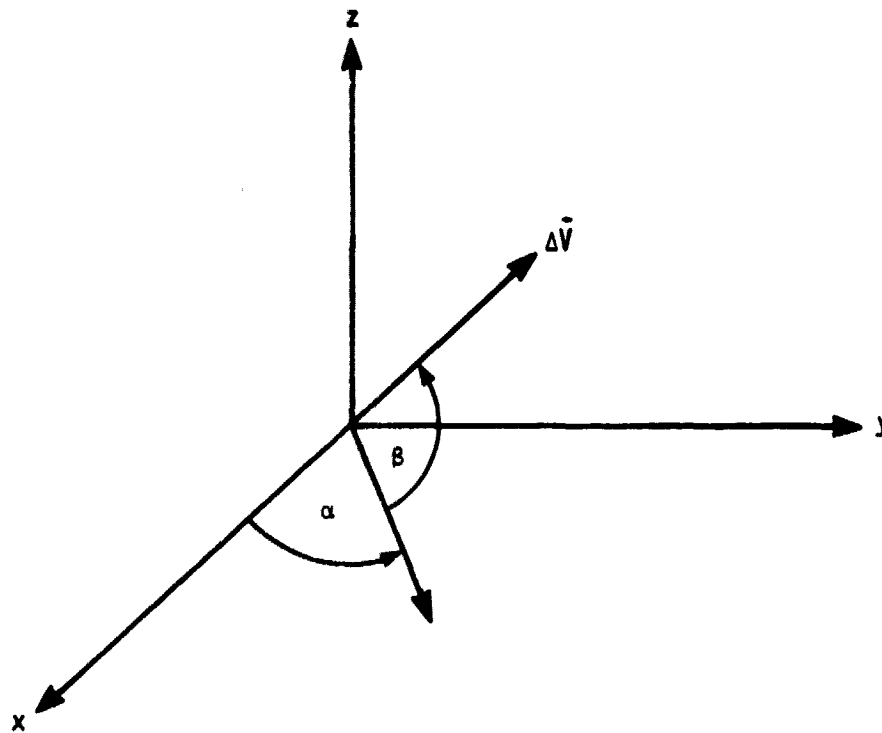
Linear interpolation was used on the reduced data to supply initial data load values for the launch azimuths of 86.25, 88.75, 91.25 and 93.75 degrees for each of the three opportunities for the first window. These cases ran satisfactorily with initial convergence obtained in not more than six iterations.

3.4 RETARGETING

The proposed method for resetting the GAMMA GUIDE preload data as necessary to compensate for launch, deployment and on-orbit delays is given in Section 7.1 of Reference 7. The on-board retargeting consists of four primary tasks:

- o Updating the SRM impulse directions.
- o Updating the SRM impulse time.
- o Updating the mission constraints.
- o Updating the initial state.

Only the first two of these tasks are addressed in Reference 7. The last task is assumed to be taken care of by the onboard navigation system. For the purpose of retargeting, the SRM impulse directions and times are calculated in a space centered inertial system (such as the M-50) and then converted over to the ECI system. This takes advantage of the fact that the impulse directions can be specified as a yaw angle α followed by a pitch angle β as shown in Figure 3-3. Thus if the spin axis of the two coordinate systems are aligned



$$\begin{aligned}\Delta \vec{V} &= (\Delta \dot{X}, \Delta \dot{Y}, \Delta \dot{Z}) \\ \Delta \dot{X} &= \Delta V \cos \beta \cos \alpha \\ \Delta \dot{Y} &= \Delta V \cos \beta \sin \alpha \\ \Delta \dot{Z} &= \Delta V \sin \beta\end{aligned}$$

Figure 3-3. IMPULSE DIRECTION FROM α, β

the transformations:

$$\alpha = \alpha' + \omega_e t$$

$$\beta = \beta'$$

can be used to relate α and β in the ECI system to α' , β' in the retargeting coordinate system; where t is a suitable time relating the two systems. In a similar manner, impulse times can be reset

$$\text{TSRM} = \text{TSRM}' + t.$$

From this preliminary study, it appears that the preload data can be implemented either in tables with linear interpolation or we can use linear equations. Although the study was accomplished in terms of launch azimuth and opportunities we note that the driving independent variable is really the time at which the Earth Centered Coordinate System, ECI, is initialized. This is particularly true for the ascending node angle Ω and the firing angle α for each burn. Note that:

- o The target elements a , e , i , ω and η can be fixed.
- o The target element Ω (ascending node angle) should be a function of the time at which ECI is initialized.
- o The initial values of α and β for each burn can be set to the values for opportunity 2. These are close enough for the algorithm to correct for opportunities 1 and 3.
- o The values of ΔV_1 , PWT3, PWT5, PWT9 and WTX can be fixed at the values for opportunity 2 also.
- o The on-board retargeting for IUS GAMMA GUIDANCE as given in Section 7.1 of Reference 7 is feasible for the Galileo Mission PL13A.

3.5 PRECISION OF CALCULATIONS

This data preload investigation used the double precision version of the MSFC GAMMA GUIDE code. Sample cases using a single precision code have been also run satisfactorily. In single precision, minor change in impulse times and directions were encountered and the cases ran in less computer time. The MSFC Univac 1108 uses a 36 bit computer word while the onboard computer is expected to use only 32 bits. This is only expected to affect those operations involving repeated divisions or the square root.

3.6 RELIABILITY AND NASA MISSIONS' OBJECTIVES

Reference 4 presented the results of a study by NSI investigating the algorithm. The report detailed various perturbation in the input parameters for the code. The perturbations were at least as severe as the expected 3 sigma values. This previous study concluded that GAMMA GUIDE could satisfactorily meet the NASA missions' objectives. This conclusion has been further strengthened by the results of this present study utilizing the improvements in the next section.

Section IV

SUGGESTED IMPROVEMENTS

4.1 INTRODUCTION

Several improvements to the GAMMA GUIDE algorithm were previously suggested in Reference 4. These have been incorporated in the MSFC code.

4.2 MINIMUM DELTA LAMBDA TEST

When the program was changed to single precision coding, an instability sometimes occurred in the calculations of the changes in the control variables $\delta\lambda$ with respect to the changes in the constraints. The constraint deviations δY would oscillate between a negative and a positive value just out of tolerance. During this time, it was noted that $\delta\lambda$ was extremely small, indicating that the best possible solution in single precision had been obtained. It is suggested that a test for minimum $\delta\lambda$ be inserted into the algorithm. This test is shown in Figure 1-3 and has been made by Boeing in the B-5 version.

4.3 MAXIMUM ITERATION RESET OF LAMBDA

Whenever the maximum iteration limit is exceeded, generally the best possible solution for the control variables λ has been obtained. However, there may arise cases in which the solution may be erroneous. To eliminate this problem, it is suggested that on beginning a guidance update cycle, the control vector λ be saved and if the iteration limit is exceeded this stored value be used. This change has been made by Boeing in the B-5 version.

4.4 TIMELINE CHECKING

This problem has been previously discussed in Reference 4, in which a minimum coast test to insure that an overlap in the time of end SRM2 burn and begin SRM3 burn did not occur. This test should be extended to the coast between any two burns. Coding for these tests have been added to the MSFC program. The timeline for the MSFC code is shown in Figure 1-1.

Section V

PROGRAM AVAILABILITY

5.1 LISTINGS, MAGNETIC TAPE AND CARD SOURCE

The programs/codes in Table 12 were used in this study and have been stored on a single PUR tape in the MSFC Tape library. See Appendix B for their use.

Table 12. PROGRAM FILES

PROGRAM	USE	FILE	CARDS APPROX.
MSFC Dev.	Development of Gamma Guide	1	4000
NSI SIXD	Spin Stage 6-D	2	1200
Boeing B-5	Onboard Gamma Guide	3	5000
Boeing Stars	Stand Alone Attitude 6-D	4	4000
NSI MOB	Thrust Tables for Gamma Guide	5	400

These programs are still under development, and are therefore changing. A copy of the latest listing can be obtained by contacting the Contracting Officer's Representative, Mr. A. W. Deaton of the System Analysis and Integration Laboratory, EL23, Marshall Space Flight Center, Alabama.

A magnetic tape suitable for use on a Univac 1108 system or a card source deck can also be supplied to authorized users.

Section VI

SAMBO MODIFICATION'S

6.1 MISSION PLANNING MODIFICATIONS

Modifications were made to the SAMBO trajectory program of Reference 8 to provide output data consistent with mission planning efforts. Usual trajectory profile data, in terms of mean orbital elements, continue to be printed in the first row. However, three additional rows of output were added. The second row gives

R(km)	...	radius magnitude of IUS/SC
V(km/s)	...	velocity magnitude
$\gamma(^{\circ})$...	flight path angle with respect to the local vertical
LAT($^{\circ}$)	...	earth geocentric latitude of IUS
LONG($^{\circ}$)	...	earth longitude of IUS
ALT(km)	...	altitude of IUS above the earth ellipsoid.
SRR(km)	...	slant range from the launch site along the earth surface to sub-satellite point.

The third row gives position and velocity vectors, in terms of the M50 Cartesian coordinate system, and the magnitude of acceleration. The M50 coordinate system is the Aries-mean-of-1950, Cartesian coordinate system with the origin at the center of the earth. The epoch is the beginning of Besselian year 1950 or Julian ephemeris date 2433282.423357. The XM50-YM50 plane (see Figure 6-1) is in the mean earth's equator of epoch and the XM50 axis is directed toward the mean vernal equinox of epoch. The ZM50 axis is directed along the earth's mean rotational axis of epoch and is positive north. The YM50 axis completes the right-handed system. The fourth row of trajectory data gives

AZI($^{\circ}$)	...	inertial heading angle of IUS inertial velocity vector measured in the horizontal plane clockwise from north.
$\beta(^{\circ})$...	the angle between the line from the earth's center to the sun and the IUS/SC's orbital plane.

A modification was also made to the tracking analysis summary option in the SAMBO program. Eleven ground tracking stations and three tracking satellites are available. Output data printed for each acquisition period has included azimuth, elevation, range and range rate of the vehicle with respect to the

station(s) selected. To this output has been added the cone angle between the vehicle longitudinal axis and the line-of-sight to the tracking station.

6.2 CONVERSION OF DATA

A user's guide to the conversion of reference data from SAMBO to input for Gamma Guide can be found in Appendix C.

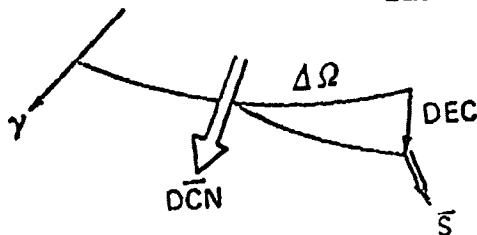


Figure 6-1. IUS PLANETARY LAUNCH GEOMETRY FOR DESCENDING LEG OPPORTUNITY

Section VII

REFERENCES

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3. "Gamma Guidance for the Inertial Upper Stage (IUS)," Hardtla, John W., Boeing Aerospace Company, AIAA Guidance and Control Conference, 7-8 August 1978, Palo Alto, California.
4. "IUS Guidance Algorithm Gamma Guide Assessment," Dauro, V. A. and Bray, R. E., Northrop Services, Inc., Huntsville, Alabama, TR-230-1960, May 1979.
5. "Gamma Guide Preset Data for the Galileo Mission PL13A," Dauro, V. A., Northrop Services, Inc., Huntsville, Alabama, M-9230-79-04, September 1979.
6. NASA Twin/Spin IUS Galileo Mission Preliminary Launch Window, Accuracy, and Tracking Analysis, EL23 (79-42), A. W. Deaton, C. D. Caryle, and H. L. Phillips, George C. Marshall Space Flight Center, Huntsville, Alabama, July 25, 1979.
7. Subsystem Design Analysis Report, Guidance Subsystem Analysis, D290-10256-1, Revision B, The Boeing Company, Seattle, Washington, June 23, 1978.
8. "SAMBO Users Manual," Williams, D. F., Northrop Services, Inc., Huntsville, Alabama, TN-240-1212, March 1974.
9. "Input Data Setup for Gamma-Guidance", Bray, R. E. and Dauro, V. A., Northrop Services, Inc., Huntsville, Alabama, M-9230-79-01, May 1979.
10. "IUS Spin Stage Six Degree of Freedom Simulation", Dauro, V. A., and Williams, B. L., Northrop Services, Inc., Huntsville, Alabama, TR-230-1954, March 1979.

Appendix A

SAMPLE DATA LOAD

This appendix presents a short listing of a sample data load for the MSFC Gamma Guide development program. Other sample data cases are stored on the PUR Tape described in Appendix B.

```

1 LAI-LON-ALT-AZM-GAM-VEL-TSTAGO / ISTG-XX-TGID-XX-TGEND-XX-XX-PRINT
28.6336 14.8489 617800.58 92.9583 .4398 25815.415 0. 1000.
1.0 2 NSIG/ TSTG WT THRST ISP AREA EXIT DELT (1 CD/ST6)
13
0. 55497.508 0. 1. 0. 0. 25.
0. 0. 1. 293.85 0. 0. 2.0
0. 0. 0. 1. 0. 0. 25.
0. 0. 1. 228. 0. 0. 20.
0. 36502.46 0. 1. 0. 0. 25.
0. 0. 1. 294.05 0. 0. 2.0
0. 0. 0. 1. 0. 0. 25.
0. 0. 1. 228. 0. 0. 20.
0. 11347.48 0. 1. 0. 0. 25.
0. 0. 1. 306.09 0. 0. 2.0
0. 0. 0. 1. 0. 0. 25.
0. 0. 1. 228. 0. 0. 20.
0. 0. 0. 1. 0. 0. 25.
3 NAMELIST INPUT
$LISTK
AA=.346,PP=.7512,PRAA=.346,PRPP=.7512,
YEAR=6*U.0,
XLO= 5591.00,0.0,21455.229,0.0,0.0,21700.0,
8421.02,0.0,0.0,30329.037,0.0,0.0,30500.0,
7481.55,0.0,0.0,30733.418,0.0,0.0,30900.0,
TEND=32800.0,
XISP1=293.85,DELVT1=3391.0000,WTX=38762.56,TB1=99.156,ATB1=99.156,
XISP2=294.05,DWSRM2=21507.0,PWT5=36490.47,TB2=150.21,ATB2=150.21,
XISP3=306.09,DWSRM3=6039.0,PWT9=11347.48,TB3=103.66,ATB3=103.66,
NAKCS=4,4,4,4,3,3,3,2,2,2,NOPT=0,0,0,0,0,0,
NIARG=1,0,1,0,1,0,0,LOOPS=1,0,1,0,0,0,ISOLO=1,
XLLIM=3*50.0,3*1.0E10,2*200.0,DT0=6*25.0,
IWRITE=0,
$END

```


6	CODE	INPUT	SCENARIO																
1	5	9	13	0	0														
2	5	9	13	0	0														
3	5	9	13	0	0														
4	5	9	13	0	0														
5	9	13	0	0	0														
6	9	13	0	0	0														
7	9	13	0	0	0														
8	9	13	0	0	0														
9	13	0	0	0	0														
10	0	0	0	0	0														
11	13	0	0	0	0														
12	13	0	0	0	0														
8	NOMINAL SRM1																		
13	.00	.00	.25	43482.57	9.00	50519.83	29.00	56484.33											
	45.00	61640.19	53.00	61097.37	59.00	59920.82	69.00	54943.43											
	89.00	33501.04	94.00	18045.31	97.00	4955.45	99.00	1074.66											
	99.21	.00																	
9	NOMINAL SRM2																		
16	.00	.00	.25	12005.81	2.00	16502.40	15.00	22032.66											
	40.00	34593.57	60.00	50428.03	80.00	56381.69	96.00	61528.19											
	104.00	60986.30	110.00	59811.94	120.00	54843.60	140.00	33440.17											
	145.00	18012.52	148.00	4946.44	150.00	1072.71	150.21	.00											
10	NOMINAL SRM3																		
16	.00	.00	.25	6488.44	2.00	7351.09	6.00	8686.84											
	15.00	11560.27	35.00	19227.60	58.00	25657.63	62.00	27952.36											
	60.00	26524.47	72.00	25706.53	80.00	22989.10	90.00	16820.03											
	100.00	5550.30	101.00	4024.61	102.00	2228.18	103.66	.00											

```

16  EARTH CONSTANTS EPS OMEG
0.  7.2922D-5
18  SET BURN 1
1  81.4939  8.1243
18  SET BURN 2
2  72.299  12.494
18  SET BURN 3
3  85.560  5.755
17  SET TARGET CONIC AND YBAR
-20123482. 2.06879  28.59204  71.07624  -83.91125  93.88088
22  COMPUTE
23  STOP

```

Appendix B USE OF PUR TAPE

ORIGINAL PAGE IS
OF POOR QUALITY

The programs/codes of Table 12, repeated below, have been stored on a single UNIVAC 1100 PUR Tape. This tape is in the program data format of the 1100 system and can be accessed by the assignment

@ASG,TJ_TAPE,U9S,XXXXX.

where XXXXX is a number that can be obtained from the Contracting Officer's Representative, Mr. A. W. Deaton, EL23, Marshall Space Flight Center, Huntsville, Alabama.

Table 12. PROGRAM FILES

PROGRAM	USE	FILE	CARDS APPROX.
MSFC Dev.	Development of Gamma Guide	1	4000
NSI SIXD	Spin Stage 6-D	2	1200
Boeing B-5	Onboard Gamma Guide	3	5000
Boeing Stars	Stand Alone Attitude 6-D	4	4000
NSI MOB	Thrust Tables for Gamma Guide	5	400

As a user aid each file has a data element called CHECKS which will execute a sample case. As an example, the following run stream will read in and execute a sample SIXD Case.

```
@ASG,TJ_TAPE,U9S,XXXXX.
@REWIND_TAPE
@MOVE_TAPE,1
@COPIN_TAPE,TPF$
@FREE_TAPE
@ADD_CHECKS
@FIN
```

The codes Boeing B-5 and boeing STARS both require a larger temporary file, if changes are to be made. This can be obtained by

```
@FREE.TPF$  
@ASC,T.TPF$,r/// 1000
```

Then repeating the run stream above with either

```
@ MOVE,TAPE,2          (For B-5)
```

or

```
@ MOVE,TAPE,3
```

To obtain a listing, the MSFC utility program LISTIT can be called by replacing the ADD option with

```
@XQT,AL,SYSS*MSFC$.LISTIT
```

Inserting the card

```
.PUNCH,SYMBOLICS
```

After the @XQT above will punch out the source statements.

Appendix C

GAMMA GUIDE INPUT DATA FROM SAMBO

Reference 9 presented a discussion of converting reference data from trajectories generated using SAMBO, to a form suitable for GAMMA GUIDE. Most of this procedure is still valid, but NSI has extended the SAMBO capability and the impulsive solution is now used by SAMBO to create a finite burn solution. Thus the times of beginning and end of each SRM burn need not be calculated. To further simplify the input, the time column of the Block 2 input may be set to zero and the program will supply these times. As an additional aid, the impulse deltas for a SRM burn can be set up by using option 18 in the MSFC version. As an example, for SRM1, the namelist block input

XLO(1) = 3391.0, XLO(2) = 0.0, XLO(3) = 0.0

with the Option 18 input below

...18

.....1.....71.2816.....7.9603

will set

XL(1) = 1077.7442 XL(2) = 3180.6942 XL(3) = 469.6091

so that

$\Delta V1 = 3391.0$

$\alpha = 71.2816$

$\beta = 7.9603$

The notes below, with the description of input contained in Reference 4, will assist the user in converting data from the SAMBO trajectories to input for GAMMA GUIDE.

SAMBO TO GAMMA
1) Convert Sambo thrust tables

- o Punch as given into GAMMA Form, Run in MOR program with time-thrust factors of 1. This converts to English units as input to MOB is in metric but its output is English.
- o Select, from output, 15-20 points for Gamma Guide and adjust thrust factor to obtain required total impulse, and ISP to obtain mass overboard.
- o Extract TB1, TB2, TB3, ISP1, ISP2, ISP3, DELVT1, DELT1, DELT2, DELT3

2) Set up initial point. Sambo units are metric.
o Conversion factors

.3048 m/ft

.45359237 kgm/lb

20925662. ft

Radius of Earth

32.174048 ft/sec²

Gravity

o Initial position

LAT - Latitude in degrees

LOH - Longitude in degrees

FOR ALTITUDE (Sambo ALT is above ellipsoidal Earth)

RMAG/.3048 - 20925662.

VMAG/.3048 - Velocity

FLTPA Flight Path Angle in degrees

AZ Azimuth in degrees.

3) Set up weights

- o Convert mass at beginning and end of each burn to obtain

PWT1

PWT3

PWT5

DWSRM2

DWSRM3

WTX

- o These may be obtained from MOB run.

4) Set up Lambdas

- o XL(4) = Time burn 1 end - DELT1
- o XL(12) = Time burn 2 end - DELT2
- o XL(20) = Time burn 3 end - DELT3
- o Set RCS psuedo burn times

o Set up impulse deltas

XL(1) = DELVT1

XL(2) = 0.0

XL(3) = 0.0

XL(9) = DELVT2

XL(10) = 0.0

XL(11) = 0.0

XL(17) = DELVT3

XL(18) = 0.0

XL(19) = 0.0

o Set burns to desired alpha, beta by using option 18 in MSFC version.

5) Set terminal position to YBAR

YBAR = XXXGE, YYGE, ZZZGE, XGDGE, YYDGE, ZZZDGE

these are already in English Units

TEND = Final time